MAT-92-02

Dust Control and Compaction of Unpaved Roads - Field Trials

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Documentation Page

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Date Published: February, 1992

Published by: Research and Development Branch, MTO

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Abstract: The report covers the field trials of two dust control agents conducted on an unpaved road near Mallorytown, Ontario in September, 1990. After the dust control agents were applied on test segments and controls, test vehicles were run over the test road and measurements were taken on the relative amount and attributes of the dust generated both immediately after application and one week later.

The results show that, for at least one week following application, Material A outperforms Material B under no precipitation. Otherwise, the two materials appear to perform the same.

A number of recommendations are made involving test approaches that should be used if further research is to be conducted.

Comments: The Ministry is currently considering the development of a decision-modelling system that would assist in the matching of the most appropriate dust control agent with the attributes of the candidate road for dust control. This approach recognizes the complexity of the subject since there are many dust control agents each of which will work under a specific range of conditions. Likewise, there is a broad range of conditions that affect dust control on Ontario's gravel roads.

Key Words: dust control, aggregates

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H. P. Cleghorn
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The Research and Development Branch
Ontario Ministry of Transportation

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February 1992

Table of Contents

Executive Summary iv

1/ Introduction 1

1.1/ Background 1

1.2/ Review of Literature Survey 1

1.3/ General Guidelines for Site Selection 2

2/ Workplan 2

2.1/ Site Selection 2

2.2/ Site Preparation 3

2.3/ Test Methodology 5

2.4/ Workplan Schedule 7

3/ Field Trials 9

3.1/ Modifications to the Workplan 9

3.2/ Dust Control Application Procedure 10

3.3/ Calibration of Hi-Vol Samplers 12

3.4/ Aggregate Soil Sampling and Analysis 12

3.5/ Meteorological Conditions - Field Observations 15

3.6/ Test Vehicle 15

3.7/ General Observations 15

4/ Results 18

4.1/ Field and Laboratory Results of Aggregate Samples 18

4.2/ Hi-Vol Sample Data 19

4.3/ Cascade Impactor Data 19

5/ Discussion 19

5.1/ Effect of Dust Control Agents on Test Roadway 19

5.2/ Effect of Meteorological Conditions 27

6/ Conclusions and Recommendations 28

6.1/ Inferences and Conclusions 28

6.2/ Recommendations 30

7/ References 31

List of Tables and Figures

Tables

1/ Size distribution of limestone used for road construction 5
2/ Mean flowrate equations for hi-vols during the field trials 14
3/ Summary of meteorological conditions during field trials 16
4/ Summary of test vehicle data 16
5/ 2nd uncontrolled section - untreated 20
6/ 2nd controlled section - Material A treatment 21
7/ Buffer section - untreated 22
8/ 1st controlled section - Material B treatment 23
9/ 1st uncontrolled section - untreated 24
10/ Summary table of particulate matter concentrations ($\mu g/m^3$) from hi-vol samples 25
11/ Particulate matter concentrations for test sections 28

Figures

1/ Cronk Woods road test site 4
2/ Application of Material A dust control agent 11
3/ Side elevation of the Material A treated road surface after application 11
4/ Application of Material B dust control agent 13
5/ Material B application and smooth drum rolling of the freshly treated surface 13
6/ Road structure 14
7/ Test vehicle and dust plume generated in the Material B treated section (September 19,1990) 17
8/ Test vehicle on the Material A treated section - no visual indication of a dust plume (September 19, 1990) 17
9/ Westerly view of the test roadway from the Material A treated section to trailer in the back ground where the Material B treated section is located 18
10/ Modified proctor - crushed stone 0 - 7/8" material 26

Executive Summary

The report covers the field trials conducted on two dust control agents, named Material A and Material B in this report, on an unpaved roadway in Cronk Woods in the Municipality of Front of Yonge. The trials took place during the period 12 September 1990 to 20 September 1990 on a roadbed made up with fresh gravel to bedrock, to a depth of approximately 12 in (0.3 m).

The trials included forward and reverse runs by a 9 ton six wheel tandem truck over 4 days of testing, which corresponded to 2 days of testing directly after surface treatment with the control agents and an additional 2 days of testing approximately one week later. In addition, roadway samples were collected from the test sections for on-site and laboratory measurements of dry density and moisture content as well as particle size distribution. Using Hi-Vol samplers, airborne particulate matter was collected to determine concentration levels of suspended particulate material upwind and downwind from the test site. A limited number of tests were conducted to determine the particle size distribution of airborne material collected at ground level near the curbside, using a cascade impactor.

The test results do not clearly indicate any loss of fines due to the movement of traffic over the Cronk Woods gravel road. The factors that could have affected the test results were:

(1) inadequate quality control during material handling (at the plant) and during placement

(2) the quantity of recovered sample for particle size distribution measurement may have been too small to be representative for the entire 2 km long roadbed

(3) the breaking down of aggregate due to the grinding and shearing of the crushed stone surfaces during the passing of traffic was dependent on traffic density

(4) as traffic rolls by, the displacement of the top material would be expected to occur thereby continuously exposing layers of virgin aggregate

Results from the Hi-Vol measurements show no obvious difference in data for the Material B or Material A treated sections, despite the fact that the observed plume was very much greater for the former compared to the latter for three of the four days of testing.

Based on these trials the following inferences were made.

- Provided Material A is allowed to cure with relatively little precipitation, it acts as an effective dust suppressant for the vehicles travelling on unpaved roads for at least a period of 1 week. On the other hand, Material B is relatively poor under similar conditions for reducing entrained dust levels in the plume. High precipitation results in a deterioration of the Material A treated surface thereby reducing its efficiency in controlling dust levels in the vehicle wake; however, it is unknown whether this process is reversible.

- The Hi-Vol measurements indicate that Material A is more effective than Material B in suppressing airborne particulate matter, for at least a period of 1 week after application. When there is only light precipitation, however, there appears to be relatively little difference in performance of these test suppressants 1 - 2 days after application.

- The dry density values tend to be greatest for treated and untreated sections after precipitation and are reduced by 2 - 5% after runs by the test vehicle. Moisture content values are reduced by approximately 10% for the Material B treated aggregate after runs by the test vehicle but there is no significant change for the Material A treated and buffer sections. The results indicate that the suppressant mechanism for Material B may be similar to that for deliquescent materials, such as calcium chloride, while Material A appears to act like a binder.

- The percentage of the silt-clay fraction stabilizes within 2 days of suppressant application, with relatively small subsequent changes. There is a corresponding reduction in the percentage gravel and an increase in the sand fraction in all three test sections.

On the basis of these findings and inferences, it was concluded that the Material A product at an application cover of 1.6 L/m^2 showed promise as a dust suppressant for control of both the dust plume in the wake of vehicles traversing unpaved roads as well as entrained dust that is dispersed and transported away from the unpaved roads. The current trials did not show the same promise for the Material B product.

The results and conclusions indicate that future testing should be re-evaluated under conditions that reduce the uncertainty with the measured data. Specific recommendations are as follows:

- make measurements of particulate concentrations in the test vehicle plume at different elevations to quantify the visual observations made in these trials;

- test longer sections (greater than 200 m for each treated section), with longer transition (buffer) sections between treated sections;
- use higher traffic densities on test sections than in the current study to induce ruts and potholes;
- conduct testing at different times of the year, specifically mid- and late summer to cover different meteorological conditions; and
- conduct additional testing of the Material A product.

1/ Introduction

1.1/ Background

This document is the final of two reports prepared for the Ontario Ministry of Transportation (MTO), Highway Engineering Division, Research and Development Branch, ref. no. I.D. 89002. The study was designed to identify and test materials suitable for dust control and compaction of unpaved roads. The first report in this series covered a literature review and manufacturers' survey of dust control methods for unpaved roads (Concord, 1990).

The work in this report covers the selection of dust control agents and subsequent field trials, including the methodology, analysis and conclusions. For this section of the study, the criteria identified during the initiation meeting in May 1989 were:

- the surface conditions at the test site should include a new gravel road surface and a crushed limestone base; and

- the field trials should be conducted with the two best dust control materials identified from a literature study. Onsite testing would include the measurement of airborne dust levels using Hivol samplers as well as moisture, mesh size and nuclear densities of gravel samples from the road surface. The trials would span a period of two to three weeks following the application of the dust control agents.

1.2/ Review of Literature Survey

The literature study indicated the following important parameters in the selection of chemical dust suppressants for use on unpaved roads.

1. Effectiveness
2. Cost
3. Environmental acceptability
   - regulatory
   - social, e.g., appearance, effect on vehicles
4. Climate and meteorological factors
5. Surface geochemistry
6. Traffic type and number
7. Ease and frequency of application

Two of these products were selected for field trials.

Material A is an ammonium lignosulphonate pulping liquor and Material B is a multi-enzyme biodegradeable formulation similar to tannin.

1.3/ General Guidelines for Site Selection

The literature survey also identified criteria for use in site selection, surface preparation, sampling and analytical methodology. Some of the key points were:

1. A preference that the selected site was located in an area with few physical obstructions such as trees, buildings, etc., as well as being relatively straight along the test sections. In addition, the prevailing wind direction would preferably be perpendicular to the roadway during the field trials and the daily traffic count should be relatively high.

2. For initial surface preparation, it was recommended that the surface be blade selected to remove loose material and to smooth ruts, potholes, etc. Following this treatment, the surface was to be compacted with a rubber-tired roller, followed by a water spray, if considered necessary, and subsequent application of the dust control agent.

3. The two basic techniques for quantifying particulate emissions from vehicular traffic on unpaved roads were identified. The techniques are fixed ground-based sampling (usually Hi-Vol samplers) and mobile, multi-point sampling in the trailing plume from a test vehicle.

The workplan described in the following chapter was therefore devised with this background information from the literature review, the manufacturers' survey and the MTO requirements regarding the selection of products for testing.

2/ Workplan

2.1/ Site Selection

The criteria used for site selection were:

1. The unpaved roadway for use in field trials had to be reasonably straight for at least 500 m, with a minimum width of approximately 8 m. These dimensions were based on the requirement that each treated section would be approximately 100 m long and that the two suppressants would be tested simultaneously. Also, the minimum width was selected to be about twice the

maximum wheelbase of the test vehicle (4 m) to ensure that curb effects are not a modifier for results obtained during testing.

2. The test roadway would have a newly-laid limestone surface and, if located near Lake Ontario, would run roughly N - S since testing was planned in the late summer (August/September). The rationale for these criteria was based on the fact that limestone surfaces generated more 'fines' than fresh pit surfaces and a new surface would reduce the number of variables that would otherwise influence the test with a previously trafficked surface. Furthermore, the majority of unpaved roads in Ontario are constructed with graded limestone. A brief survey of the late summer wind rose patterns for southern Ontario in an area from Toronto to Cornwall showed that during the daytime, winds were predominantly easterly off the lake and the St. Lawrence River and their direction was reversed at nighttime.

3. The test site should be relatively clear of trees, buildings, high curbs and other obstructions to ensure that the factors controlling the dispersion of airborne particulate road dust are primarily based on the meteorology and the source at the time of testing.

Based on these criteria, a site was chosen in Mallorytown on Cronk Woods Road and its location is illustrated in Figure 1. This site was estimated to be less than 10 km from the St. Lawrence River and the roadway runs NNE - SSW.

2.2/ Site Preparation

Testing was scheduled over 11 days from September 12, 1990 to September 22, 1990. It was arranged that engineers from the suppliers of Materials A and B would supervise and coordinate the application of their products to ensure that this phase of the program was conducted as effectively as possible and according to manufacturer's specifications.

The new limestone surface used for testing was bladed and tire rolled under the supervision of Mr. Ross Walker, Superintendent for Roads, Township of Front of Yonge, whose department has direct responsibility for the maintenance and upkeep of roads in the region.

The site was located on a section of Cronk Woods road that was being resurfaced by removing the old surface down to about 12 in (0.3 m), which was close to bedrock, and replacing it with a 6 in (0.15 m) base of 3 in (0.08 m) mesh crushed limestone and a top 6 in (0.15 m) layer of 7/8 in (0.02 m) mesh crushed limestone, obtained from the Lawson (Athens) quarry, no. 15-45-0, and the Wood's quarry, no. B15-134-0. The former is in the March formation and the latter in the Oxford formation. It is estimated that

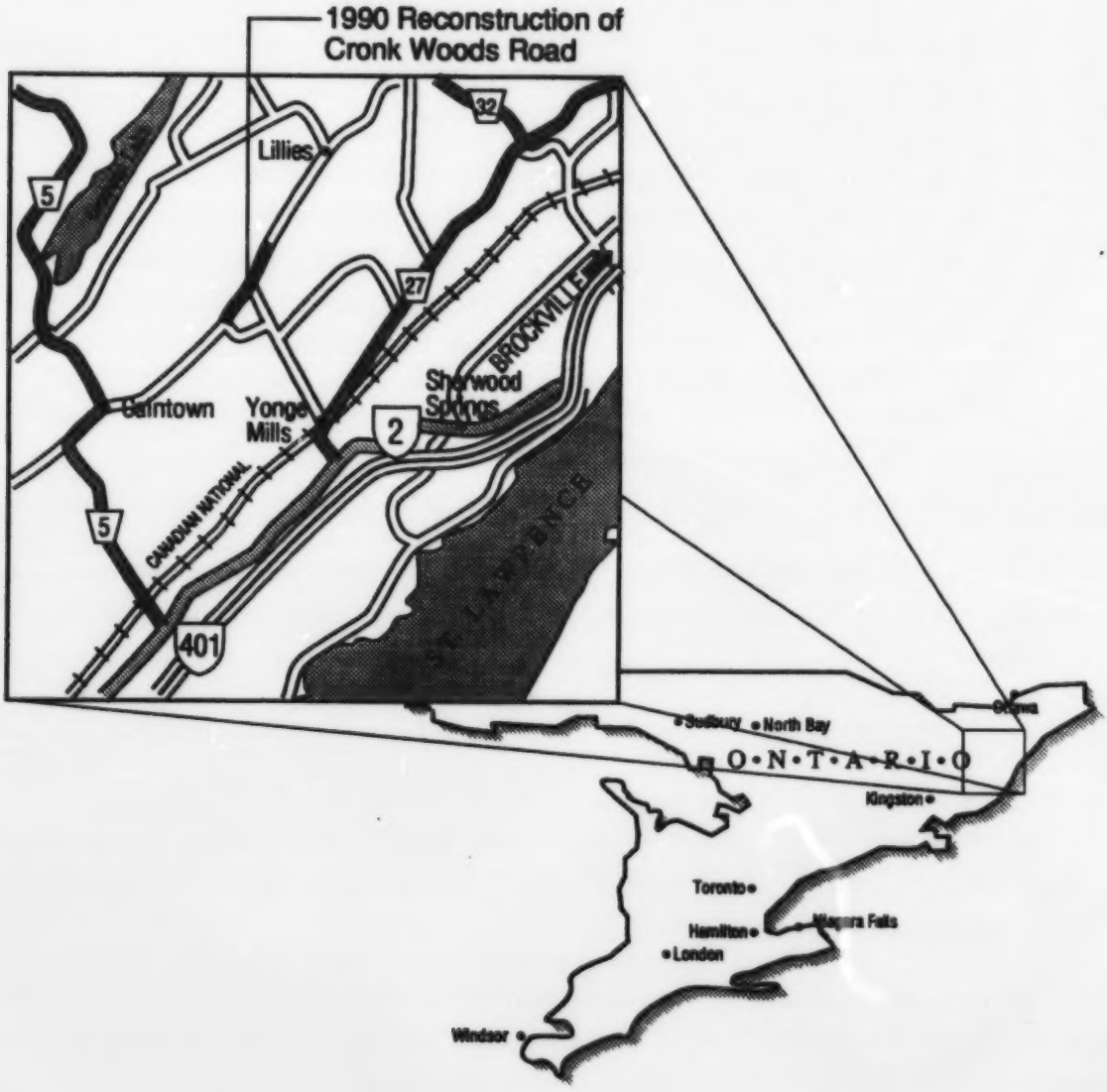

Figure 1/ Cronk Woods road test site

Table 1/ Size distribution of limestone used for road construction

GRANULAR A LIMESTONE 7/8 in mesh		GRANULAR B LIMESTONE 3 in mesh	
Mesh Size (mm)	Amount passing (%)	Mesh Size (mm)	Amount passing (%)
106	100	106	100
22.4	100	22.4	68.5
16	91	16	n/a
9.5	64.8	9.5	n/a
4.75	42	4.75	30.7
1.18	21.9	1.18	14.1
300 µm	13.6	300 µm	9.9
75 µm	8.8	75 µm	6.8

Data from a telephone conversation, H. P. Cleghorn to Bill Berman, Manager, Tackeberry Construction, 14 November, 1991.

the stone used for the roadway was a mix of approximately 75/25 Wood's/Athens quarry limestone. Limestone specifications are presented in Table 1.

Prior to field trials, the roadway and curb had been profiled to ensure good drainage: the surface had also been rolled and treated with water to achieve 100% compaction. Because of the timing for these field trials, members of the Concord team were not present during placement of the new surface. Furthermore, there was no stockpile of the material that could be sampled for laboratory testing.

2.3/ Test Methodology

The roadway was subdivided into five 100 m test sections, without intermediate transition areas, because of the limited number of sites that were available to meet the timetable for program completion. The test sections were labelled as follows, running SSW to NNE approximately:

Label	Treatment
1st Uncontrolled	No treatment
1st Controlled	Material B
Buffer	No treatment
2nd Controlled	Material A
2nd Uncontrolled	No treatment

Test procedures for trials were developed in concert with the Ministry of Transportation research team as well as McGill University Geotechnical Institute staff. The McGill staff would conduct the following measurements.

1. Nuclear density and moisture content.
2. Particle size distribution of the road surface.
3. Load carrying capability.

The purpose of these tests was to determine:

- whether the roadbed was placed and compacted uniformly;
- if further compaction occurred during the movement of traffic;
- if loosening up of the roadbed occurred during the movement of traffic; and
- the extent of fines production resulting from movement of traffic.

The following ASTM on-site field sampling and tests were selected to provide spot checks for moisture content and *in situ* density measurements of aggregate to meet these requirements. They were based on adaptations of the following ASTM procedures:

1. ASTM D75, Practice for sampling Aggregates.
2. ASTM D1556, Test Method for Density of Soil in place by the Sand-Cone Method.
3. ASTM D2167, Test Method for Density and Unit Weight of Soil in place by the Rubber Balloon Method.
4. ASTM D2922, Test Methods for Density of Soil and Soil Aggregate and Rock in place by Nuclear Methods (Shallow Depth).
5. ASTM D3017, Test Method for Water Content of Soil and Rock in place by Nuclear Methods (Shallow Depth).

Laboratory testing of the collected aggregate samples was based on the following ASTM procedures.

6. ASTM D2216, Laboratory Determination of Water (Moisture) Content of Soil, Rock, and Soil-Aggregate Mixtures.
7. ASTM D422, Particle Size Analysis of Soils.

8. ASTM D2217, Wet Preparation of Soil Samples for Particle Size Analysis and Determination of Soil Constants.

9. ASTM D1557, Moisture-Density Relations of Soils and Soil-Aggregate Mixtures using 10 lb (2.49 kg) Rammer and 18 in (457 mm) Drop.

Ambient air sampling for total suspended particulate matter was conducted by using 8 Hi-Vol samplers located approximately 25 m away from either side of the roadway, at an elevation of approximately 2 m. The configuration used was based on the assumption that easterly winds would be predominant during the test program therefore 2 samplers were to be installed for each controlled section on the west northwesterly side of the roadway at approximately one third and two thirds the length of the test section. On the east southeasterly side, a single sampler was installed midway along the length of the section. The remaining 2 samplers were installed on either side of the roadway, midway along the length of the buffer section. The samplers were located in this manner for the following reasons:

a) the distance and elevation used in testing correspond to the near optimum siting for Hi-Vol probes (Environment Canada, 1988);

b) the Hi-Vol samplers were located using this configuration to obtain simultaneously both background (upwind) and downwind as well as cross-wind dispersed particulate matter; and

c) it was believed that by using as many as 8 samplers any interferences arising from the fact that there were no transition areas between the 5 sections could be identified and isolated from the final results.

Samples for size analysis measurements of airborne particulate matter were collected on a cascade impactor, located midway along the length of each controlled section at a distance of approximately 3 m from the roadway and an elevation of appproximately 0.9 m.

A traffic counter was installed to determine the number of vehicles as a functon of time. This information was used to supplement visual observations especially of the 9 ton truck used for testing.

2.4/ Workplan Schedule

The following schedule was proposed.

September 12, 1990

Morning — Installation of Hi-Vol samplers. Road closure to local traffic.

	Collection of aggregate samples for moisture content and *in situ* density measurements. Collection of samples for laboratory compression ratio measurements.
	Application of Material A and Material B in their respective sections. Compaction of applied products using a smooth drum and tire drum compactors. Allow to dry.
Afternoon	Start up of Hi-Vol samplers and cascade impactor.
	Collection of aggregate samples for moisture content and *in situ* density measurements. Collection of samples for CBR measurements.
September 13, 1990	
Morning	Opening of road to local traffic. Run test truck approximately 50 times each way along the entire test section.
	Collection of aggregate samples before and after test truck runs for moisture content and *in situ* density measurements. Collection of samples for laboratory CBR measurements.
	Note wind direction, weather conditions, e.g., overcast or sunny, gusty or still, etc.
Afternoon	Removal and replacement of Hi-Vol filters (sampling time approximately 24 h).
	Collection of aggregate samples for moisture content and *in situ* density measurements. Collection of samples for laboratory CBR measurements.
September 14, 1990	The procedure used on the previous day was repeated.
September 20, 1990	The procedure used on September 13 was repeated.
September 21, 1990	The procedure used on September 14 was repeated.
September 22, 1990	No further application of the test dust suppressants was planned to determine what changes would occur after a week of elapsed time. It was planned that field testing would be concluded on September 22.

3/ Field Trials

3.1/ Modifications to the Workplan

The workplan and schedule were modified to accommodate specific site conditions. These modifications were made to resolve operational problems on-site such as power availability as well as those problems specific to the site such as traffic volume and conditions of the roadbed. Specifically, these modifications were:

1. There was only one Hydro power source from a house located nearly midway along the length of the test roadway. The remaining power requirements were met by use of 3 portable gasoline-operated generators.

2. There was thick and relatively tall shrubbery on the westerly side of the test section treated with Material A; consequently, the two Hi-Vol samplers were located 2 - 3 m from the edge of the roadway instead of the targeted 25 m.

3. Only 2 of the 8 Hi-Vol samplers were in operation by late afternoon on September 12, 1990. By the following day, 7 units were fully operational and all 8 units functioned effectively for the remaining days of the field trials.

4. The uncovered, untreated curbs and drainage areas alongside the roadway resulted in relatively high levels of airborne dust that could not be readily factored into measurements from the Hi-Vol samplers.

5. Because of the threat of heavy rain in the area, tests were conducted on September 19 and 20 instead of the September 20, 21 and 22.

6. Because of limitations of on-site power, a single cascade impactor was operated only on 2 days, September 19 and 20 respectively. The alternative was to replace one or 2 of the Hi-Vols with the cascade impactor. Since a comprehensive set of Hi-Vol measurements was considered to be more important for these trials, it was decided to limit testing to a single cascade impactor operating on each of the last 2 days of the trials when there was adequate power to operate all the Hi-Vols as well as this unit.

7. The volume of local traffic was very much lighter than anticipated for the 8 days covering these tests: the main impact on the treated surfaces was primarily due to passes by the test vehicle. Although this reduced the number of variables for the program, it was uncertain whether the net effect on the treated road surface was influenced to a greater extent by the

meteorological conditions than by the traffic. Also, for this reason, all Hi-Vol units were operated only during the day and were inactivated between late evening (20:00h to 21:00h) and early morning (07:30h to 08:30h) on September 13, 14, 19 and 20.

8. The 1st uncontrolled section (next to the Material B treated section) was inadvertently treated with calcium chloride by the road maintenance crew on the evening of September 13 for dust control. To achieve consistency, it was agreed that this section as well as the 2nd uncontrolled section (next to the Material A treated section) would also be calcium chloride treated prior to testing on September 19 and 20. Despite the relatively short test sections, it was judged that this modification had little or no effect on the efficiencies of the dust suppressants used for these trials, based on visual observations before and after calcium chloride application.

9. No field or laboratory CBR testing was conducted. This decision was made in the absence of a proper, stable reaction frame to perform a meaningful field CBR test. Although the use of a truck as a reaction frame was considered, it was decided that safety requirements could not be met. Furthermore, since the bedrock was relatively close to the surface, it was concluded that both field and laboratory CBR measurements were unlikely to give a good indication of road deterioration because of the rigid bedrock boundary and its effect on the "pressure bulb" from the CBR penetrating probe.

3.2/ Dust Control Application Procedure

Material A was applied by a 12 ft (3.6 m) spray bar from a tanker supplied by the manufacturer and was supervised by their representative. The material application coverage was 1.6 L/m^2 on average, based on 3 passes with a premixed 35% concentrate on the left and right hand lanes respectively. Since there was overlap in the middle lane, it was estimated that coverage in that lane was near 2.4 L/m^2. Material A is treacly in appearance with a sugar-sweet odour.

Collection of aggregate for moisture content and *in situ* density measurements as well as laboratory samples for moisture content, dry density and particle size measurements were made in the test and buffer areas on September 12, before application of the two suppressants and in the afternoon after partial "cure" of Material A. No surface moisture was observed on visual examination of aggregate collected from the Material B treated roadbed.

Following application of the material, and partial drying, the surface was compacted by a smooth drum roller and allowed to dry for approximately 24h before opening the road to local traffic.

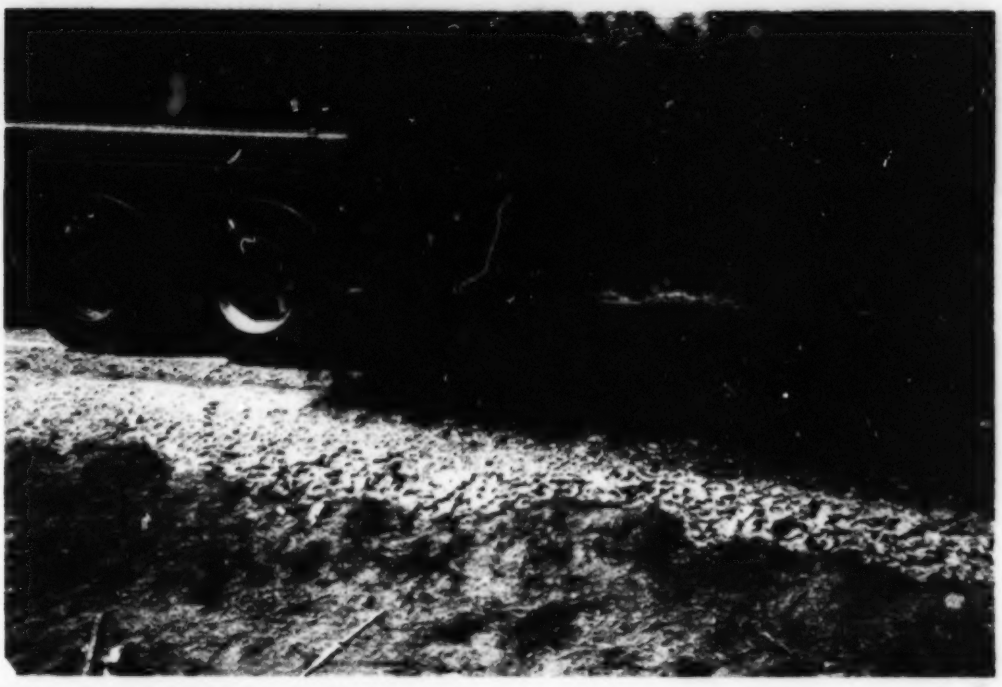

Figure 2/ Application of Material A dust control agent

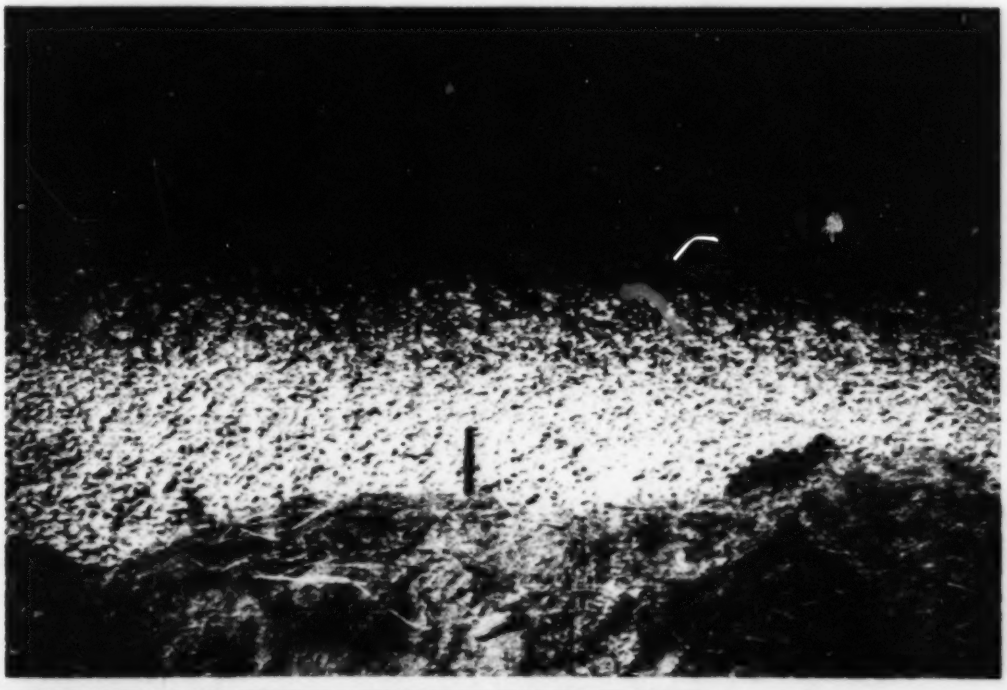

Figure 3/ Side elevation of the Material A treated road surface after application

Figures 2 and 3 illustrate the method of application and road surface appearance following application and rolling.

Material B was premixed on-site by addition of 10 U.S. gallons of the super concentrate to 1500 imperial gallons (approx 1700 USG) in a water tank attached to a dump truck and the material was gravity-fed to a 8 ft (2.4 m) spray bar for application to the road surface. The total complement was applied and the surface was smooth drum rolled after each pass, followed by a `wobble-wheel' tire drum roller after full application. Estimated coverage, assuming a 50% concentrate, was 0.1 L/m^2. The application and compaction were supervised by a representative of the manufacturer.

The material appeared to be completely miscible with water and during application had the appearance of a weak, white emulsion. There was no detectable odour. The road was kept closed to local traffic for approximately 24h following application despite assurances by the representative that this precaution was unnecessary.

Figures 4 and 5 illustrate the method of application and road surface appearance during compaction.

3.3/ Calibration of Hi-Vol Samplers

Pressure drop measurements using a digital manometer were conducted on each unit in Concord's laboratory prior to and on completion of the field traials. On each day of the field trials at start up in the mornings and shutdown in the evenings, pressure drop measurements were made using an inclined plane manometer. The mean flow rate calibration data covering the test period are summarised in the equations presented in Table 2.

3.4/ Aggregate Soil Sampling and Analysis

The aggregate materials used in the upgrade of the Cronk Woods road are illustrated in Figure 6. The stone was good quality crushed limestone, from the Lawson and Wood's quarries that are local to the area and had been passed for concrete and asphalt aggregate by the Ministry of Transportation (MTO), Kingston. The top 6 inches (152.4 mm) consisted of 7/8" (22 mm) crushed limestone and met MTO specifications for Granular A stone: the next 6 in down to bedrock consisted of 3 in stone, which met Granular B specifications. Although the Lawson quarry stone is composed of "softer" limestone than material from the Wood's quarry, it was anticipated that the 75/25 Wood's/Lawson mix used for the roadbed would have good aggregate quality.

To minimize the destruction of the road surface when sampling, the size of the collected samples for

Figure 4/ Application of Material B dust control agent

Figure 5/ Material B application and smooth drum rolling of the freshly treated surface

Table 2/ Mean flowrate equations for hi-vols during the field trials

Hi-Vol Ident	Flow rate calibration equation
1581	Flowrate (CFM) = 5.56 P (in. H2O) + 3.86 @ 35 CFM, maximum devn = ± 1.0 CFM (3%)
1582	Flowrate (CFM) = 5.62 P (in. H2O) + 2.03 @ 35 CFM, maximum devn = ± 5.2 CFM (15%)
1583	Flowrate (CFM) = 6.11 P (in. H2O) + 17.48 @ 35 CFM, maximum devn = ± 0.02 CFM (0.1%)
1584	Flowrate (CFM) = 12.61 P (in. H2O) - 23.21 @ 35 CFM, maximum devn = ± 9.0 CFM (25%)
1585	Flowrate (CFM) = 6.34 P (in. H2O) + 18.74 @ 35 CFM, maximum devn = ± 0.06 CFM (0.2%)
1523	Flowrate (CFM) = 4.13 P (in. H2O) + 18.53 @ 35 CFM, maximum devn = ± 0.06 CFM (0.2%)
1524	Flowrate (CFM) = 6.49 P (in. H2O) + 19.42 @ 35 CFM, maximum devn = ± 0.17 CFM (0.5%)
1527	Flowrate (CFM) = 5.49 P (in. H2O) - 5.86 @ 35 CFM, maximum devn = ± 0.03 CFM (0.1%)

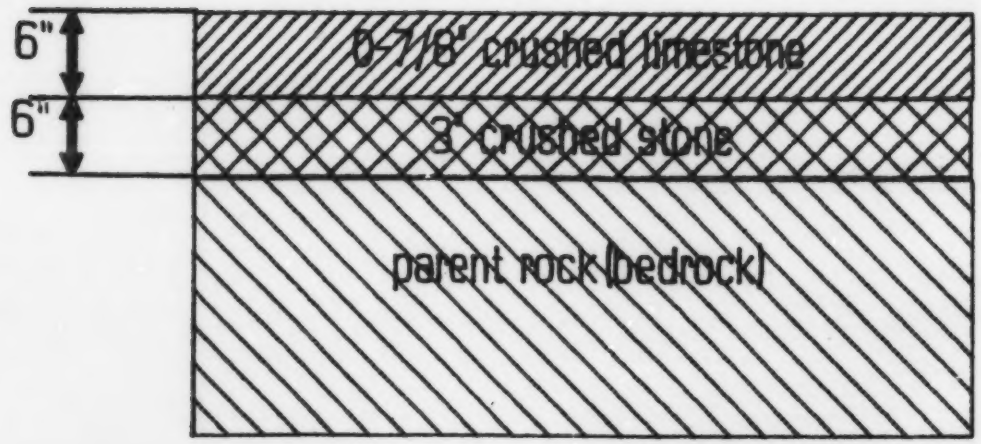

Figure 6/ Road structure

laboratory testing was smaller than as directed by ASTM procedures. The sampling depth was to a maximum of 3 inches (76.2 mm) below the road surface.

The instrument utilized in obtaining *in situ* measurements of both moisture content and density was a Troxler 3440 Moisture Density Gauge. All measurements with this equipment were achieved by the direct transmission mode at a minimum depth of 2 inches (50.8 mm).

3.5/ Meteorological Conditions - Field Observations

Visual observations made on-site during testing are listed in Table 3.

3.6/ Test Vehicle

Conditions used for test vehicle runs are summarized in Table 4. An illustrative photograph of the vehicle and the dust plume generated in the buffer section is shown in Figures 7 and 8.

The total vehicle count for forward and reverse passes over the test section from 14:00h on September 13 to 14:00h on September 20 was 2,615. In general, the frequency was greatest between 06:00h and 20:00h, with peak values between 10:00h and 17:00h. Traffic was relatively heavy on September 17 and 18 compared to the other days. A panoramic view of the roadway showing the Material A treated section in the foreground is presented in Figure 9.

3.7/ General Observations

The following general observations were noted during testing:

(1) the test vehicle speed of 40 kph may have been too slow; however, this limitation was based on the maximum available length for the each test section and the requirement to complete tests on two products simultaneously;

(2) there was insufficient traffic to generate any ruts or potholes during testing;

(3) there was "carry over" dust between sections. An ideal solution would have been to have longer test sections with a longer transition area between each test section; and

(4) based on a visual examination, the Material A treated section appeared in general to exhibit the least amount of fugitive dust.

Table 3/ Summary of meteorological conditions during field trials

Date	Observations
12 September	Sunny, clear and warm Light SW wind Heavy overnight dew
13 September	Overcast and warm Light to no wind Heavy overnight dew
14 September	Overcast and gusty conditions Mainly south to south-westerly winds
19 September	Little or no precipitation from Sept 14 - 19 Overcast and cloudy. Some sunny periods Mainly west to south-westerly winds
20 September	Heavy overnight precipitation Mainly clear in morning. Overcast with light rain in the afternoon. Mainly east to north-easterly winds

Table 4/ Summary of test vehicle data

Date	Speed	Total Number*		
13 September	25 kph	24	start:	11:20h
			end:	12:05h
	40 kph	10	start:	12:10h
			end:	12:30h
14 September	40 kph	100	start:	10:30h
			end:	13:30h
19 September	40 kph	100	start:	11:25h
			end:	14:28h
20 September	40 kph	100	start:	10:45h
			end:	13:41h

*Total number includes forward and return passes of vehicle over the test roadway.

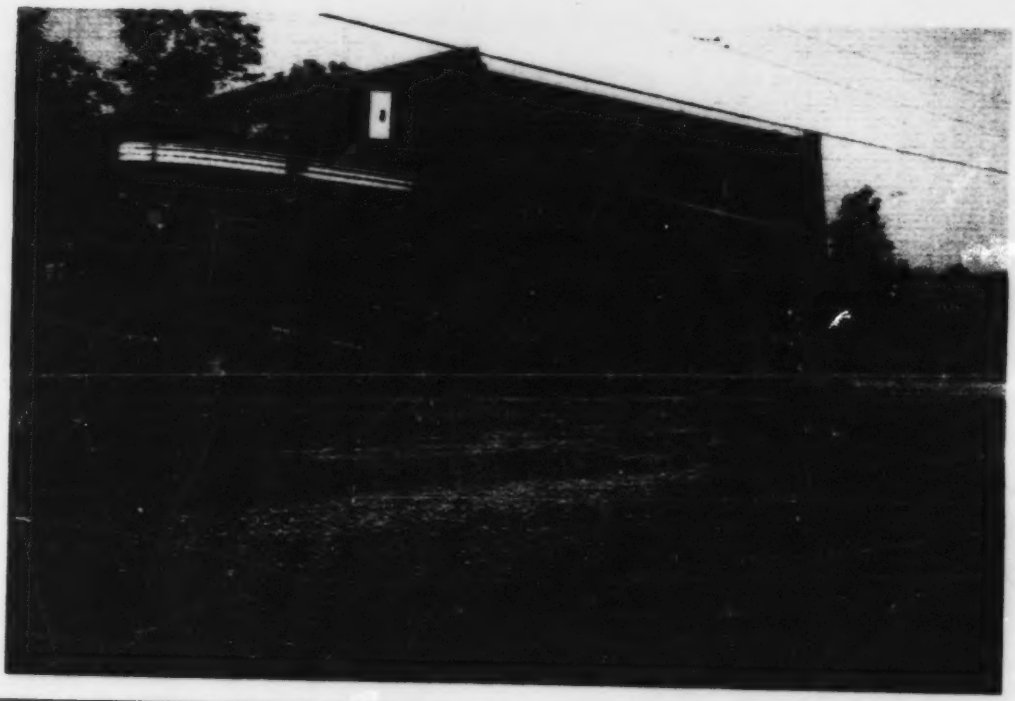

Figure 7/ Test vehicle and dust plume generated in the Material B treated section (September 19, 1990)

Figure 8/ Test vehicle on the Material A treated section - no visual indication of a dust plume (September 19, 1990)

Figure 9/ Westerly view of the test roadway from the Material A treated section to trailer in the background where the Material B treated section is located

In addition, during the heavy rain on the early morning of September 20, Material A appeared to form `pools' on the road surface, which were subsequently washed away. The impact of this was that a much greater plume was exhibited during testing on that day which could not be distinguished in general from the test vehicle plume in the other sections.

4/ Results

4.1/ Field and Laboratory Results of Aggregate Samples

The moisture content and corresponding dry density measurements obtained with the use of the Troxler nuclear gauge for the various test sections are summarized in Tables 5 to 9. The moisture content measured in the laboratory from the recovered aggregate samples in general confirmed the Troxler values. Several sand-cone and rubber balloon density measurements were conducted in the field to confirm the Troxler gauge. Figure 10 illustrates the moisture-density relationship of the 0-7/8" crushed stone. The majority of the field density measurements are between 90%-100% of modified proctor.

Tables 6 to 9 list the percent gravel, sand and silt + clay (fines). The amount of material considered fines varies from approximately 9% to 11% with a few exceptions.

4.2/ Hi-Vol Sample Data

A summary of the total suspended particulate matter concentration data from Hi-Vol sampling on September 13, 14, 19 and 20 is presented in Table 10.

4.3/ Cascade Impactor Data

Cascade impactor measurements were scheduled to determine the particle size distribution of material that is deposited near the curbside as a result of traffic on the treated and untreated sections. These measurements would be directly dependent on the airborne transient and long-term dispersed particulate matter. In the former case, the probability of capture on the impactor is greatest at ground level, close to the source, whereas the probability of capture is greatest at elevations near 2 m and at distances near 25 m from the source for the latter.

No significant change in weight was noted on the cascade impactor filters. This result underscores the fact that the traffic density was low during these field trials with the consequent low probability of capture of the transient airborne particulate matter resulting from traffic.

5/ Discussion

5.1/ Effect of Dust Control Agents on Test Roadway

The test results do not clearly indicate any loss of fines due to the movement of traffic over the Cronk Woods gravel road. The factors affecting the test results were as follows:

(1) inadequate quality control during material handling (at the plant) and during placement;

(2) the quantity of recovered sample for particle size distribution measurement may have been too small to be representative of the entire 2 km long roadbed;

(3) the breaking down of aggregate due to the grinding and shearing of the crushed stone surfaces during the passing of traffic was dependent on traffic density; and

(4) as traffic rolls by, the displacement of the top material would be expected to occur thereby continuously exposing layers of virgin aggregate.

Table 5/ 2nd uncontrolled section - untreated

Sample I.D.	Description	Date Sampled	Dry Density (mg/m^3)	Moisture Content (%)		Particle Size Distribution		
				Nuclear	Sampling	Gravel (%)	Sand (%)	Silt + Clay (%)
	"as is"	12/09/90	2.19	3.0				
	before running 9 ton truck	13/09/90	2.31	3.1				
J	after running 9 ton truck	13/09/90	2.11	3.5	2.7	53.4	37.4	9.2
	before running 9 ton truck	14/09/90	2.17	2.9				
N	after running 9 ton truck	14/09/90	2.20	1.9	2.2	50.1	40.1	9.8
S	19/09/90 treated with $CaCl_2$ - after running truck	20/09/90	2.29	3.2	2.5	44.0	44.3	11.7

Table 6/ 2nd controlled section - Material A treatment

Sample I.D.	Description	Date Sampled	Dry Density (mg/m^3)	Moisture Content (%)		Particle Size Distribution		
				Nuclear	Sampling	Gravel (%)	Sand (%)	Silt + Clay (%)
A	before application	12/09/90	2.30	2.8	3.3	54.3	36.7	9.0
B	before application	12/09/90	2.22	2.3	1.4	67.0	26.9	6.1
E	after application	12/09/90	2.15	4.2	2.5	53.3	36.2	10.5
	before running 9 ton truck	13/09/90	2.15	3.3				
I	after running 9 ton truck	13/09/90	2.22	3.4	2.5	54.7	36.0	9.3
	before running 9 ton truck	14/09/90	2.27	3.0				
M	after running 9 ton truck	14/09/90	2.19	3.5	2.3	58.4	32.0	9.6
R1	after running 9 ton truck	20/09/90	2.22	3.4	2.5	51.9	38.9	9.2
R2	100 mm below surface	20/09/90			3.1	45.5	45.1	9.4
R3	150 mm below surface	20/09/90			3.3	49.3	41.5	9.2

Table 7/ Buffer section - untreated

Sample I.D.	Description	Date Sampled	Dry Density (mg/m^3)	Moisture Content (%)		Particle Size Distribution		
				Nuclear	Sampling	Gravel (%)	Sand (%)	Silt + Clay (%)
C	"as is"	12/09/90	2.1	3.2	1.6	56.7	35.4	7.9
	before running 9 ton truck	13/09/90	2.18	2.7				
H	after running 9 ton truck	13/09/90	2.01	3.3	2.4	49.6	41.5	8.9
	before running 9 ton truck	14/09/90	2.19	2.8				
L	after running 9 ton truck	14/09/90	2.17	2.9	2.3	41.9	47.4	10.7
Q	after running 9 ton truck	20/09/90	2.19	3.0	2.6	49.2	40.9	9.9

Table 8/ 1st controlled section - Material B treatment

Sample I.D.	Description	Date Sampled	Dry Density (mg/m^3)	Moisture Content (%)		Particle Size Distribution		
				Nuclear	Sampling	Gravel (%)	Sand (%)	Silt + Clay (%)
D	after application	12/09/90	2.22	4.1	5.1	45.8	45.0	9.2
	before running 9 ton truck	13/09/90	2.17	3.3				
G	after running 9 ton truck	13/09/90	2.13	2.9	2.5	55.3	36.1	8.6
	before running 9 ton truck	14/09/90	2.12	4.1				
K	after running 9 ton truck	14/09/90	2.15	3.4	2.5	45.3	43.9	10.8
P	after running 9 ton truck	20/09/90	2.23	3.1	2.9	37.3	52.4	10.3

Table 9/ 1st uncontrolled section - untreated

Sample I.D.	Description	Date Sampled	Dry Density (mg/m^3)	Moisture Content (%)		Particle Size Distribution		
				Nuclear	Sampling	Gravel (%)	Sand (%)	Silt + Clay (%)
	"as is"	13/09/90	2.18	3.3				
F	after running 9 ton truck	13/09/90	2.09	5.8	3.3	41.5	47.5	11.0
	$CaCl_2$ treated after running 9 ton truck	14/09/90	1.99	2.4				
D	19/09/90 treated with a $CaCl_2$ - after running truck	20/09/90	2.12	3.5	2.4	47.1	42.8	10.1

Table 10/ Summary table of particulate matter concentrations ($\mu g/m^3$) from hi-vol samples

Sampler	1524	1581	1527	1583	1584	1585	1523	1582
13 September 1990								
Total Suspended Particulate Concentration	65.4	48.9	29.9	118.6	227.0	n.d.	54.5	213.0
14 September 1990								
Total Suspended Particulate Concentration	93.3	114.7	406.1	229.0	596.0	238.6	96.8	550.4
19 September 1990								
Total Suspended Particulate Concentration	403.0	44.1	696.3	46.9	497.0	583.5	37.5	776.5
20 September 1990								
Total Suspended Particulate Concentration	8.0	37.2	21.6	38.5	52.9	7.2	46.7	76.2

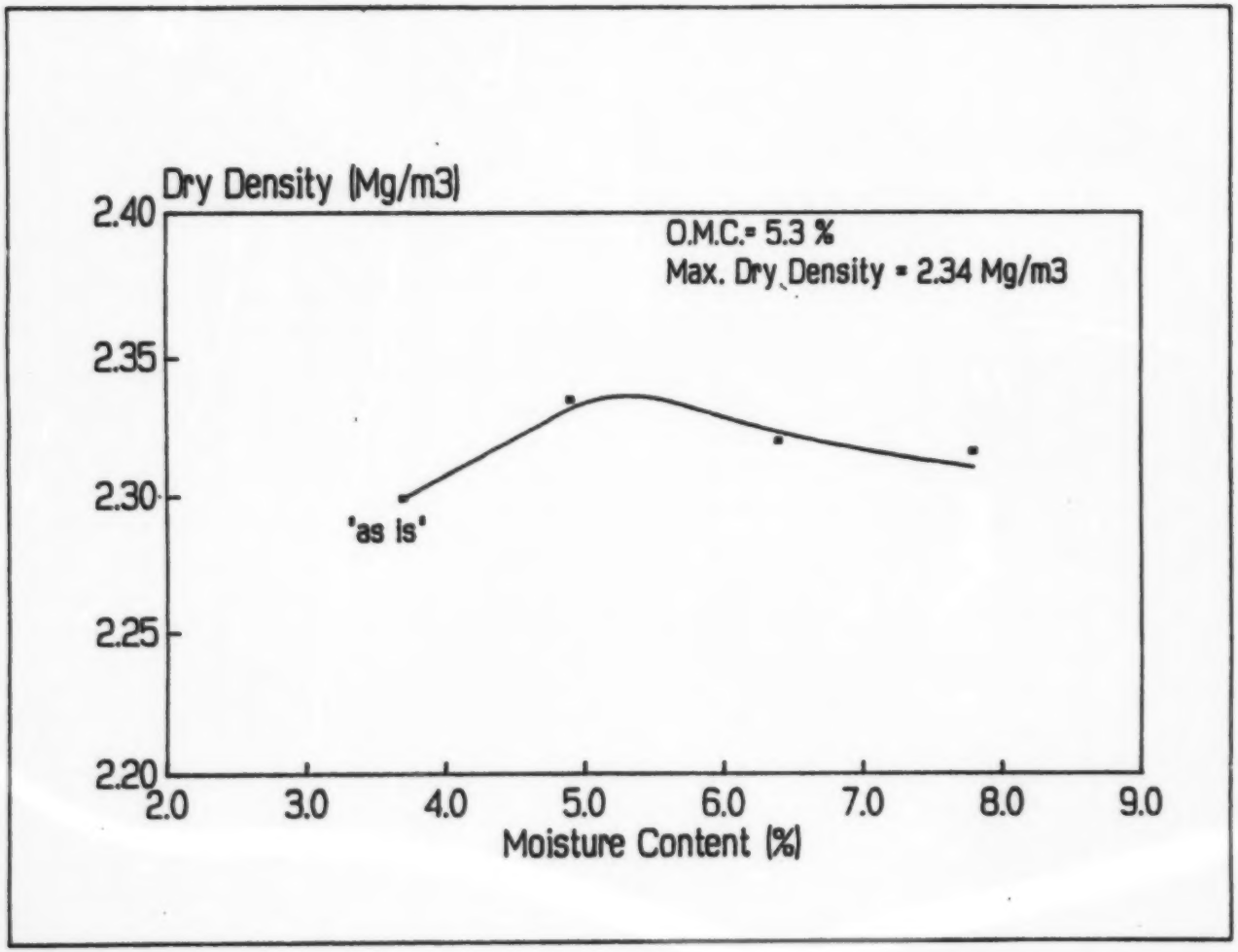

Figure 10/ Modified proctor - crushed stone 0-7/8" material

5.2/ Effect of Meteorological Conditions

Based on values reported in the literature, in which the simple Gaussian Plume model was used, the estimated dust emission factor for a vehicle travelling at 40 kph (25 - 30 mph) is approximately 1.0 lb/vehicle-mile or 0.3 kg/vehicle-km (Cowherd et al., 1974). Also, conditions were mainly overcast for most of the test period with slight solar radiation which corresponds to a D stability with moderate winds (less than 5 m/s). For light winds (less than 1.5 m/s), this corresponds to a C stability. Based on wind rose data for Brockville, it is estimated that wind speeds were generally greater than 1.5 m/s, except for conditions on September 13 when there was relatively no wind. It should be noted however, that no direct comparison between on-site ground level wind speeds and the Brockville data can be made because the latter were obtained at an elevation greater than 30 m above ground level.

The Gaussian model that has been used elsewhere for estimating downwind concentrations is shown in equation 5.1 (Concord, 1990).

$$c(x,z) = \frac{Q}{(2\pi)^{\frac{1}{2}}\sigma_2 u}\left[\exp\left(-\frac{(z-h)^2}{2\sigma_2^2}\right)+\exp\left(-\frac{(z+h)^2}{2\sigma_2^2}\right)\right]$$

where:

c= particulate concentration

Q= source strength of a continuous source

z= height above ground

x= downwind distance normal to the road

u= wind velocity

h= effective height of the plume after mixing in the automatic wake

σ= standard deviation of the particle's vertical displacement

Based on an emission factor of 0.3 kg/vehicle-km, the estimated emission rate over the 500 m test section from the test vehicle is 6.67 mg/m.s travelling at a constant speed of 40 kph. Assuming a mixing height of approx 25 - 30 m and wind velocity of 1.5 m/s, then the estimated maximum downwind concentration during testing was 2000 g/m^3. The Hi-Vol data presented Table 10 have been recalculated to show mean values where two samplers were used in the same orientation for a

test section. Results for the two samplers located at approximately 2 m from the Material A treated section have been used as the basis to calculate the estimated concentrations at 25 m. These values are presented in Table 11. The results show no obvious difference in data for the Material B or Material A treated sections, despite the fact that the observed plume was very much greater for the former compared to the latter for three of the four days of testing. There were no particle size data from the cascade impactor tests to determine whether the observed plume consisted mainly of large particles that did not remain airborne for a long enough period to be dispersed and captured on the Hi-Vol filters.

Table 11/ Particulate matter concentrations for test sections

Date	Sept. 13	Sept. 14	Sept. 19	Sept. 20
Material B				
Part. Concn ($\mu g/m^3$)				
Upwind	49	115	44	*15
Downwind	*48	*251	*550	37
Buffer				
Part. Concn ($\mu g/m^3$)				
Upwind	119	229	47	7
Downwind	–	239	583	38
Material A				
Part. Concn ($\mu g/m^3$)				
Upwind	54.5	97	38	*22
Downwind	*73	*283	*212	47

Notes: *Mean value of two concentrations.

Mean values for Material A are normalized to represent levels approximately 25 m from the test section, which corresponds to roughly one-third the measured values at 2 m.

Reversal of wind direction for data presented for September 20.

6/ Conclusions and Recommendations

6.1/ Inferences and Conclusions

Particulate matter concentrations of upwind and downwind Hi-Vol samples were relatively small, but essentially the same for both treated sections on September 13 - the first day after treatment application, with only very light overnight traffic. On September 14, which corresponded to the first full day of trials, the measured concentrations were similar for both treated sections; however, downwind concentrations were generally almost double the upwind values.

On September 19, one week after application of the two test suppressants, downwind concentrations were almost an order of magnitude greater than the upwind values. Furthermore, downwind concentrations for the Material B section were almost double the values for the Material A section. Concentrations on September 20 were consistently small and comparable for both sections.

Particulate concentrations measured by Hi-Vols adjacent to the central "buffer" section appeared to closely track the highest values recorded in all sections for each day. Results on September 14 were similar for both upwind and downwind measurements, reflecting the gusty conditions and indicating that the differences recorded for the Material A versus Material B sections may have been even more dramatically favourable in terms of Material A dust suppressant efficiency under steady wind conditions.

From these results, it may be inferred that provided Material A is allowed to cure with relatively little precipitation during that period, it acts as an effective dust suppressant for the entrained dust plume in the wake of vehicles on unpaved roads for at least a period of 1 week. On the other hand, Material B is relatively poor under similar conditions for reducing entrained dust levels in the plume. High precipitation results in a deterioration of the Material A treated surface thereby reducing its efficiency in control of dust levels in the plume; however, it is unknown whether this process is reversible, resulting in the recovery of the surface after subsequent curing in dry conditions.

It is also inferred from the Hi-Vol measurements that Material A is more effective than Material B in suppressing dispersed airborne particulate matter, for at least a period of 1 week after application, when there is only light precipitation. However, there appears to be relatively little difference in performance of these test suppressants 1 - 2 days after application. The impact of precipitation and subsequent drying on the subsequent control effectiveness of dispersed airborne particulate matter is unknown from these trials. Particulate matter measurements on September 20 were consistently small, possibly reflecting the overcast and relatively humid conditions.

Dry density measurements for the Material A, centre "buffer" and Material B treated sections were: 2.15 - 2.22; 2.01 - 2.19; and 2.12 - 2.23 mg/m^3 respectively. In all cases, the highest values were recorded on September 20 (following heavy nighttime precipitation) and there was a trend for a reduction in dry density of 2 - 5% after runs by the test vehicle. Moisture content based on nuclear measurements for these sections corresponded to 3.0 - 3.4; 2.7 - 3.3; and 2.9 - 4.1 respectively, with approximately 10% reduction in moisture for the Material B after runs by the test vehicle and no obvious change for the Material A treated and buffer sections. These results indicate that the suppressant mechanism for Material B may be similar to that for deliquescent materials, such as calcium chloride. On the other hand, it is not surprising that Material A appears to act like a binder.

Results for particle size distribution show stabilization of the percentage of the silt-clay fraction within 2 days of suppressant application, with relatively small subsequent changes. The reduction of the percentage gravel and the percentage increase in the sand fraction are in step for samples collected in all three test sections and show no unexpected trend.

We therefore conclude that the Material A product at an application cover of 1.6 L/m^3 shows promise as a dust suppressant for control of both the dust plume in the wake of a vehicle traversing an unpaved road as well as entrained dust that is dispersed and transported away from the unpaved road. The current trials did not show the same promise for the Material B product.

6.2/ Recommendations

The test procedure needs to be re-evaluated under conditions that reduce the uncertainty with the measured data. Specifically, it is recommended that future testing be conducted as follows:

- measure particulate concentrations in the plume of the test vehicle at different elevations to quantify some of the visual observations in the present series of tests;
- test longer sections (greater than 200 m for each treated section), with longer transition (buffer) sections between treated sections;
- ensure higher traffic densities on test sections to induce ruts and potholes; and
- schedule testing at different times of the year, specifically mid- and late summer to cover different meteorological conditions.
- focus testing primarily on the Material A product as it appears to show greatest promise; however, additional controlled testing could be considered using the Material B product to determine the following:
  - suppressant characteristics to determine the method of action; and
  - the optimum application coverage and frequency. For example, because of its apparent similarity in properties to deliquescent solids, the application procedure and post-treatments currently used for calcium chloride might also be appropriate for Material B.

7/ References

Concord, 1990. Literature Review and Manufacturer's Survey on Dust Control Methods for Unpaved Roads. Prepared for Ontario Ministry of Transportation, R&D Branch, June 1990.

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